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Searches for the Higgs boson at the Tevatron collider

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Abstract

The D0 and CDF experiments at the Tevatron have sought the Higgs boson in data collected till 1996, and have set limits to its existence.
After a major upgrade of both detectors and substantial improvements of the acceleration complex, the two experiments have restarted collecting physics quality data in early 2002. It is expected that a Standard Model Higgs boson with mass lower than 180 GeV will be either discovered or ruled out with five years of running.

1 Introduction

Collider experiments at Fermilab, CERN, and elsewhere in the last decade have established the Standard Model (SM) as the *right* theory for particle physics at the energy scale of the vector boson masses. However, the building is still missing a cornerstone: as of yet we do not know what is the mechanism responsible for the breaking of the $SU(2) \times U(1)$ symmetry.

Electroweak symmetry breaking in the SM demands the existence of a neutral scalar boson H°. In alternative, theories such as the minimal supersymmetric extension of the SM (MSSM) require the existence of at least five physical boson fields (denoted as h, H°, A, $H^{\pm}$). In this paper we will only deal with searches for SM and MSSM Higgs bosons.

In the SM the couplings of the Higgs boson to the other fields are known, but its mass is a free parameter. However, triviality arguments and vacuum stability requirements indicate the range $130 < M_H < 200$ GeV as the most theoretically founded. In the MSSM the situation is different. While there are no theoretical lower bounds for the Higgs masses, there is a strict upper bound on the mass of the lightest scalar, which at tree level must not exceed M_Z. Radiative corrections increase this value to as much as 130 GeV at one loop, owing to incomplete cancellation of top and stop quark loops[1].

The 14 TeV LHC collider is expected to start data taking in the year 2007. Before that date, the D0 and CDF experiments plan to collect enough data to be able to either discover the SM H° boson (or the lightest MSSM boson) or to exclude its existence, if its mass is lighter than about 180 GeV.

2 Searches in Run I

A SM Higgs boson was sought by D0 and CDF in 110 pb^{-1} of $p\bar{p}$ collisions at 1.8 TeV by looking for associated production with a vector boson, which constitutes the most promising reaction. All possible signatures of vector boson decay were considered in events containing a pair of b-jets, which represents the dominant decay channel of the Higgs boson if $M_H < 135\ GeV$. The resulting cross section limits are summarized in fig. 1.

Several different signatures were sought for the production of MSSM Higgs bosons. The process $p\bar{p} \to b\bar{b}\phi \to b\bar{b}b\bar{b}$ ($\phi = h, H, A$) has a sizable cross section for large $tan\beta$. This was exploited by CDF in a search for events with four b jets, which resulted in the limit shown in fig. 2 (left). The H^+ boson was sought in $t\bar{t}$ decays, where it may be detected directly or indirectly for small or very large values of $tan\beta$; the mass limits obtained by D0 and CDF are shown in fig. 2 (right).

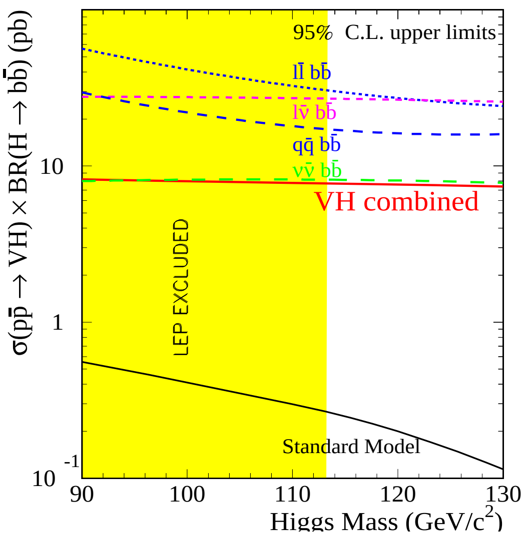

Figure 1: *Cross section limits to SM $H°$ boson production in association with vector bosons obtained by CDF in Run I. The red line is the combined result of four independent searches.*

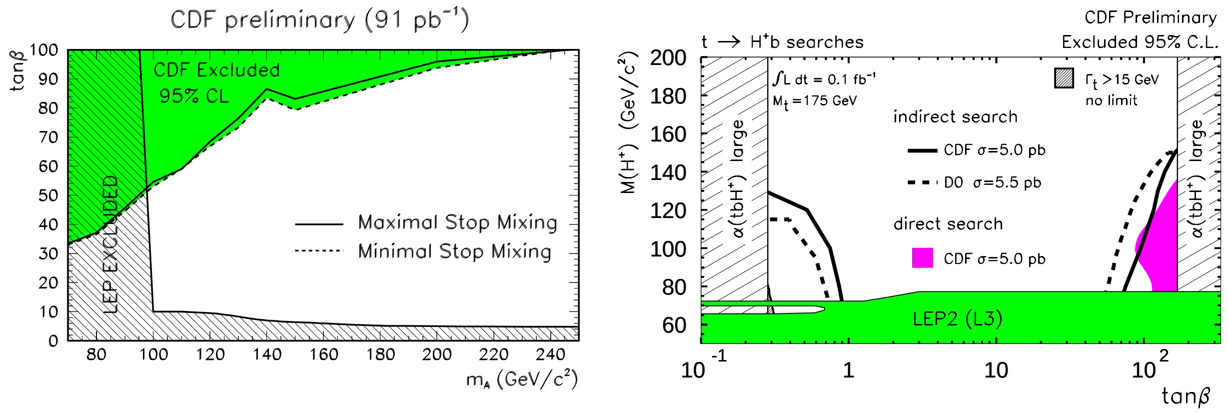

Figure 2: *Left: mass limits on MSSM neutral Higgs boson production as a function of $tan\beta$, obtained by CDF in Run I from the analysis of four-jet events; right: mass limits on H^+ as a function of $tan\beta$ obtained by direct and indirect searches in $t\bar{t}$ decays by D0 and CDF in Run I.*

3 Run II expectations

Between 1996 and 2001 both D0 and CDF have undergone massive upgrades to maximize their discovery potential. CDF now features a eight-layer silicon tracking, complete muon coverage up to $|\eta| < 1.5$, and a new online trigger for b jets. D0 has also increased its b identification capabilities, with a new $2T$ solenoid, inner silicon tracker, and outer fiber tracker.

Run I experience helped focusing the collaborations' efforts on the issues most critical for Higgs discovery. Among these, jet energy resolution and b identification deserve a few words.

The reconstruction of a $b\bar{b}$ resonance is difficult in hadronic collisions, but has been proven feasible by the observation of $Z \to b\bar{b}$ decays (fig. 3, left). In order to ease the detection of bumps in background-rich dijet mass spectra, CDF has developed a new jet correction algorithm which uses calorimeter as well as tracking and shower-max information to improve energy resolution (fig. 3, right).

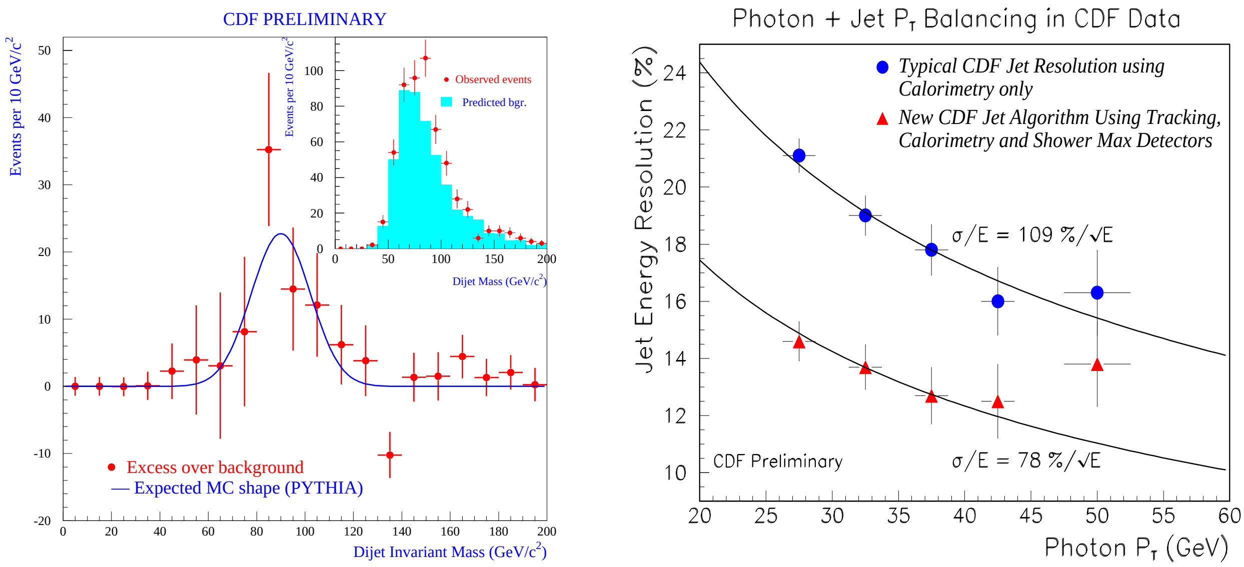

Figure 3: *Left: the $Z \to b\bar{b}$ signal observed by CDF in Run I; right: jet energy resolution as a function of photon P_T, as determined in photon plus jet events before and after the new jet corrections devised at CDF.*

In Run II the search for the Higgs boson at both D0 and CDF will profit from powerful tracking systems able to identify b decay vertices with high efficiency inside hadronic jets. CDF has upgraded its data acquisition with the SVT, a system performing $r - \phi$ silicon tracking in less than 10 μs and determining track impact parameter with a total resolution of $48\mu m$. SVT-based triggers have already proven invaluable for the collection of large samples of heavy flavor decays (see fig. 4, left), and will tremendously help in the hunt for the Higgs boson.

4 Conclusions

Between 1998 and 2000 a workshop studied the perspectives of Fermilab experiments for Higgs physics in Run II[1]. Despite some approximations and simplifying assumptions, the results are a credible estimate of the discovery potential of the Tevatron experiments. At $M_H = 115\ GeV$ a few fb^{-1} should be enough for either excluding or confirming the controversial LEP II signal (fig. 4, right). With 20 fb^{-1} the region probed for a SM Higgs boson extends up to a mass of 180 GeV; that amount of integrated luminosity would also allow to cover the MSSM parameter space up to $\sim 250\ GeV$.

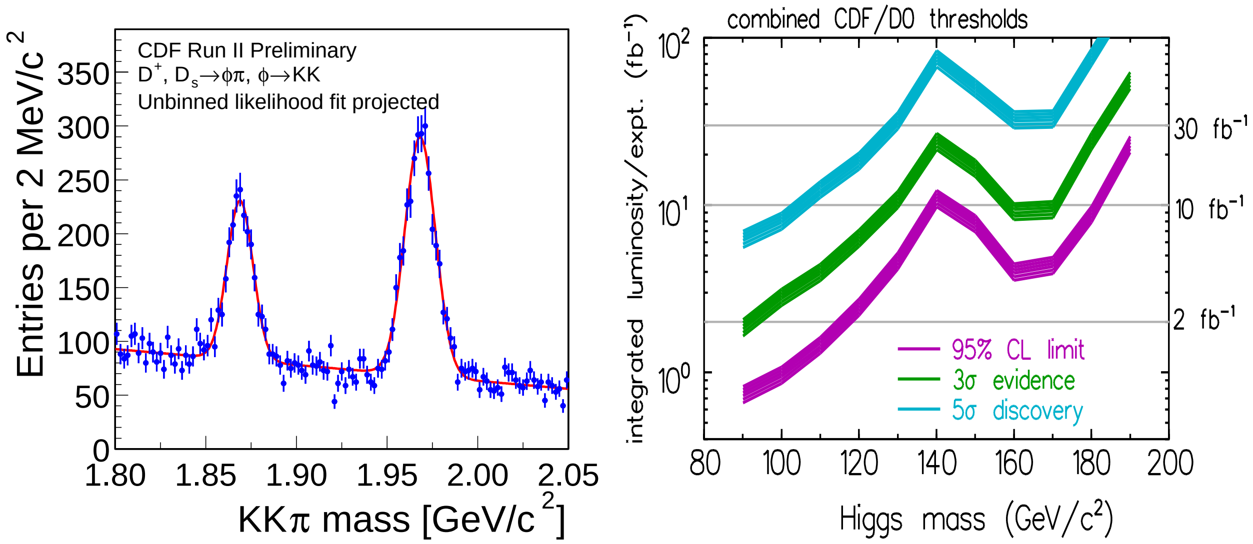

Figure 4: *Left: reconstructed mass of $K^+K^-\pi$ candidates collected with a SVT-based trigger; right: expected mass limits and discovery reach of Tevatron experiments for a SM Higgs boson as a function of collected integrated luminosity per experiment.*

References

[1] M. Carena *et al.*, *Report of the Higgs Working Group of the Tevatron Run 2 SUSY/Higgs Workshop*, HEP-PH/0010338.